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MATHEMATICAL MODELLING REPORTS

This new section, which we hope will become a permanent feature of *Mathematical Modelling*, is aimed to provide our readers with the title, abstract and other essential data concerning mathematical models that were reported on in other journals, and as selected by our editors. Our readers are encouraged and requested to submit for publication reports of additional mathematical models, in the form here presented. Our own survey extends only to scientific journals published by Pergamon Journals; although our readers are invited to contribute from any other source by submitting a tearsheet or good-quality camera-ready copy of the title page including the abstract direct from the journal concerned, providing permission to reproduce has been obtained. Please send all such submissions to: Dr D. N. P. Murthy, Department of Mechanical Engineering, University of Queensland, St Lucia, Brisbane, Qld 4067, Australia.

Biometrics Vol. 41, pp. 691–701, 1985

A STOCHASTIC MODEL OF INSECT PHENOLOGY FOR A POPULATION WITH SPATIALLY VARIABLE DEVELOPMENT RATES

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Abstract— State agencies conduct annual surveys to evaluate insect development as a component of integrated pest management programs. Precise timing of insecticide applications can be a key ingredient of such programs. A model is developed to predict insect development as a function of temperature history and other environmental variables. The model serves as the basis of a Dirichlet-multinomial distribution describing the number of larvae in a sample that are likely to have reached discrete observable life stages. The analysis incorporates the spatial variation in larval development from sampling point to sampling point within a site, which is superimposed upon the multinomial distribution of the observed development of larvae in each sample. For the spruce budworm population considered, it was found that for samples of twenty or more larvae the variation in larval development from point to point within a site, and not the number of larvae collected, controlled the information pertaining to regional larval development provided by such samples.

Biometrics Vol. 41, pp. 745–750, 1985

SOME EXTENSIONS OF A LINEAR MODEL FOR CATEGORICAL VARIABLES

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Abstract— The Grizzle–Starmer–Koch (GSK) model is extended to include the traditional log-linear model and a general class of Poisson and conditional Poisson distributions. Estimators of the model parameters are defined under general exact and stochastic linear constraints.

Biometrics Vol. 41, pp. 711-725, 1985

A GENERAL NONINTERACTIVE MULTIPLE TOXICITY MODEL INCLUDING PROBIT, LOGIT, AND WEIBULL TRANSFORMATIONS

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Abstract—A multiple toxicity model for the quantal response of organisms is constructed based on an existing bivariate theory. The main assumption is that the tolerances follow a multivariate normal distribution function. However, any monotone tolerance distribution can be applied by mapping the integration region in the n-dimensional space of transforms on the n-dimensional space of normal equivalent deviates. General requirements to noninteractive bivariate tolerance distributions are discussed, and it is shown that bivariate logit and Weibull distributions, constructed according to the mapping procedure, meet these criteria. The univariate Weibull dose- response model is given a novel interpretation in terms of reactions between toxicant molecules and a hypothetical key receptor of the organism.

The application of the multiple toxicity model is demonstrated using literature data for the action of γ-benzene hexachloride and pyrethrins on flour beetles (*Tribolium castaneum*). Nonnormal tolerance distributions are needed when the mortality data include extreme response probabilities.

Biometrics Vol. 41, pp. 727-732, 1985

A STATISTICAL MODEL FOR THE STUDY OF SELF-FERTILIZATION IN PLANTS

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Abstract—A model is proposed for the study of plant breeding where the self-fertilization rate is of importance. The model can be used to provide convenient maximum likelihood estimation of the self-fertilization rate and allelic frequencies in a parental population and its pollen pool. The self-fertilization rate can also be allowed to vary with genotype or other characterists of a plant. A simple example illustrates the methodology.

Adv. appl. Probabil. Vol. 17, p. 367-385, 1985

ON THE OPTIMAL COMPOSITION OF ELECTRICITY GRIDS WITH UNRELIABLE UNITS: SOLVABLE MODELS

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Abstract—For a large electricity grid comprising many units (plants) of various types, such as coal, oil, nuclear, hydro, etc., with known unreliabilities (outage rates) we study the optimal (i.e. the cheapest) total capacity, or numbers, of each type of unit. Existing treatments of the problem involve numerical methods and approximations of unknown accuracy. For a range of cases, we find explicit solutions. This extends the known explicit solutions, which are confined to completely reliable units. The cases we analyse are (I) a demand (load) which has a shifted Rayleigh distribution—a good approximation to the real load–duration curve—with some restriction on reliability (big units are more reliable) and (II) an exponential load distribution—which is unrealistic—with no restrictions on reliability. In both cases, the solutions reduce to transformed versions of the exact solutions for totally reliable units and, like the latter, can be exhibited by means of a cost polygon.

Load distribution curve, reliability, optimal mixture, Weibull distribution.

J. R. statist. Soc. Part 1, Vol. 148, pp. 1–36, 1985

SPATIAL STRUCTURE AND SPATIAL INTERACTION: MODELLING APPROACHES TO THE STATISTICAL ANALYSIS OF GEOGRAPHICAL DATA

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Abstract—This paper examines, by example, approaches to the statistical analysis of spatial structure and spatial interaction in geography. Both static and dynamic models are discussed with an emphasis on models that derive from geographical theory. Two themes are emphasized and developed: first, the need to accommodate mutual dependencies between elements of structure and interaction flows; second, for dynamic analysis, the need to take explicit account of the speed ("fast"/"slow") with which the elements of any spatial system adjust. The paper concludes with a discussion of research problems.

Key Words—Spatial structure, spatial interaction, time series analysis, spatial autocorrelation, entropy maximization, nearest neighbour models, spatial price theory, Kalman filters.

SIAM Rev. Vol. 27, No. 1, March 1985

PATTERN GENERATION IN SPACE AND ASPECT

SIMON A. LEVIN and LEE A. SEGEL

Abstract—A survey is presented of theories for the generation and maintenance of spatial pattern in reaction-diffusion equations and their generalizations. Applications are selected from the biological sciences and physical chemistry. Special emphasis is placed on nonlocal interaction, as manifested by the inclusion of terms involving higher derivatives or integrals. It is stressed that traditional ideas of spatial pattern generation can usefully be extended to the study of pattern in general descriptive ("aspect") variables, particularly in understanding ecological diversity and heterogeneity.

Key Words—Pattern formation, reaction-diffusion, diffusion, mathematical biology, population ecology.

SIAM Jl appl. Math. Vol. 45, No. 2, April 1985

SOME REDUCIBLE MODELS OF AGE DEPENDENT DYNAMICS

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Abstract—Three models of age dependent dynamics are developed which can be reduced to systems of ordinary differential equations. These include the cohort model, which is based on the Easterlin hypothesis, the welfare-cohort model and the weighted cohort model. It is shown that the behavior of solutions of the cohort model approaches that of the first order difference equation modeling populations with discrete, nonoverlapping, generations as the net maternity function of the cohort model approaches the Dirac delta function. It is shown for relatively flat maternity functions that the weighted cohort model more readily produces persistent oscillations than does the cohort model.

SIAM Jl appl. Math. Vol. 45, No. 1, February 1985

A MATHEMATICAL MODEL OF THE CHEMOSTAT WITH A GENERAL CLASS OF FUNCTIONS DESCRIBING NUTRIENT UPTAKE

G. J. BUTLER and G. S. K. WOLKOWICZ

Abstract—A model of the chemostat involving n microorganisms competing for a single essential, growth-limiting substrate is considered. Instead of assuming the familiar Michaelis–Menten kinetics for nutrient uptake, a general class of functions is used which includes all monotone increasing uptake functions, but which also allows uptake functions that describe inhibition by the substrate at high concentrations.

The qualitative behaviour of this generalized model is determined analytically. It is shown that the behaviour depends intimately upon certain parameters. Provided that all the parameters are distinct (which is a biologically reasonable assumption), at most one competitor survives. The substrate and the surviving competitor (if one exists), approach limiting values. Thus there is competitive exclusion. However, unlike the standard model, in certain cases the outcome is initial condition dependent.

Adv. appl. Probabil. Vol. 17, pp. 347–366, 1985

A CLASS OF CORRELATED CUMULATIVE SHOCK MODELS

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Abstract—In this paper we define and analyze a class of cumulative shock models associated with a bivariate sequence $\{X_n, Y_n\}_{n=0}^{\infty}$ of correlated random variables. The $\{X_n\}$ denote the sizes of the shocks and the $\{Y_n\}$ denote the times between successive shocks. The system fails when the cumulative magnitude of the shocks exceeds a prespecified level z. Two models, depending on whether the size of the nth shock is correlated with the length of the interval since the last shock or with the length of the succeeding interval until the next shock, are considered. Various transform results and asymptotic properties of the system failure time are obtained. Further, sufficient conditions are established under which system failure time is new better than used, new better than used in expectation, and harmonic new better than used in expectation.

First-passage times, new better than used, new better than used in expectation, harmonic new better than used in expectation, cumulative damage.

Bull. math. Biol. Vol. 47, No. 2, pp. 263–272, 1985

MOMENTS AND ORDER STATISTICS OF EXTINCTION TIMES IN MULTITYPE BRANCHING PROCESSES AND THEIR RELATION TO RANDOM SELECTION MODELS

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Abstract—We investigate the circumstances under which the moments of the order statistics of the extinction times of a set of independent branching processes exist. This extends a result of Schuster and Sigmund, *Bull. math. Biol.* **46**, 11–17, 1984, which was found in a special random selection model. Furthermore we discuss the existence of the expectation of extinction times of multitype branching processes and extend well known results for irreducible processes to the reducible case.

Adv. appl. Probabil. Vol. 17, pp. 443–459, 1985

ON THE LIMIT BEHAVIOR OF CERTAIN QUANTITIES IN A SUBCRITICAL STORAGE MODEL

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Abstract—The limit behavior of the content of a subcritical storage model defined on a semi-Markov process is examined. This is achieved by creating a renewal equation using a regeneration point $(i_0, 0)$ of the process. By showing that the expected return time to $(i_0, 0)$ is finite, the conditions needed for the basic renewal theorem are established. The joint asymptotic distribution of the content of the storage at time t and the accumulated amount of the unmet (lost) demands during $(0,t)$ is then established by showing the asymptotic independence of these two.

Total demand lost, Markov chains, semi-Markov processes, ϕ-irreducibility, ergodicity, renewal theory, storage level.

SIAM Jl appl. Math. Vol. 45, No. 3, June 1985

SOLUTION OF A TWO-DIMENSIONAL COCHLEA MODEL USING TRANSFORM TECHNIQUES

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Abstract We study the propagation of waves on the basilar membrane, a thin elastic plate immersed in the fluid-filled inner ear, using a two-dimensional linear model. Since the basilar membrane has an exponentially increasing compliance, Fourier transforming these equations gives rise to an unusual boundary value problem for an analytic function in the complex plane. We describe a general technique for solving such equations and apply it to the cochlea model. The resulting expression for the Fourier transform can be used to deduce important features of the cochlea wave. This approach also serves as the basis for an efficient numerical method to approximate the cochlea wave using fast Fourier transforms.

SIAM Jl appl. Math. Vol. 45, No. 3, June 1985

A MATHEMATICAL MODEL OF THE CHEMOSTAT WITH PERIODIC WASHOUT RATE

G. J. BUTLER, S. B. HSU and PAUL WALTMAN

Abstract—In its simplest form, the chemostat consists of several populations of microorganisms competing for a single limiting nutrient. If the input concentration of nutrient and the washout rate are constant, theory predicts and experiment confirms that at most one of the populations will survive. In nature, however, one may expect the input concentration and washout rate to vary with time. In this paper we consider a model for the chemostat with periodic washout rate. Conditions are found for competitive exclusion to hold, and bifurcation techniques are employed to show that under suitable circumstances there will be coexistence of the competing populations in the form of positive periodic solutions.

Biometrika Vol. 72, No. 2, pp. 281–291, 1985

A GENERAL CLASS OF MODELS FOR STATIONARY TWO-DIMENSIONAL RANDOM PROCESSES

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Abstract—A parametric family of spectral density-covariance function pairs for stationary spatial processes is introduced. The spectral densities are rational functions of elliptic forms along with factors in the numerator that may be of mixed hyperbolic, parabolic or elliptic form. The resulting covariance functions are linear combinations of modified Bessel functions of the second kind, which have been shown to be the natural basis for two-dimensional covariance functions (Whittle, 1963). Recursive computation techniques make calculation of the covariance functions feasible for even the most complicated models. Stochastic differential equations are used to provide a physical basis for the models as well as to develop methods for generation of the resultant processes. The results provide a step toward development of a general theory and methodology for the identification and estimation of two-dimensional processes to parallel the rational spectral density/autoregressive-moving average approach for one-dimensional processes.

Key Words—Anisotropy, rational spectral density, spatial process, stochastic differential equation.

Bull. math. Biol. Vol. 47, No. 2, pp. 205–213, 1985

STUDY OF AGE DEPENDENT HALF-LIFE OF IODINE IN MAN: A REINFORCEMENT–DEPLETION URN MODEL

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Abstract—An urn contains balls of s different colors. The problem of the reinforcement of a specified color and random depletion of balls has been considered by Shenton (1981, 1983). In this paper, the theory is applied to the biological age dependent half-life of radioactive iodine in man; the data of Cook and Snyder (1965) is used. The intake of radioactive iodine and its retention subsequently is studied.

Bull. math. Biol. Vol. 47, No. 2, pp. 231–238, 1985

EXPANSION OF THE MASTER EQUATION FOR A BIOMOLECULAR SELECTION MODEL

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Abstract—A stochastic model based on Eigen and Schuster's theory of biomolecular self-replication is studied by treating the master equation with the system-size expansion technique. The steady-state results are found to be in good agreement with the previous results and with those derived from the principle of detailed balancing. Multispecies competition and coexistence are studied carefully with the conclusions that a stable steady state is predicted for the former and a metastable state for the latter. The stochastic selection processes are also analyzed and discussed.

Bull. math. Biol. Vol. 47, No. 2, pp. 287–293, 1985

ON LINEAR STOCHASTIC COMPARTMENTAL MODELS IN DISCRETE TIME

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Abstract—This note presents a general time-dependent study of linear stochastic compartmental models in discrete time. The transient distribution of the state of the system is obtained by adapting methods used in the continuous time analysis. Covariance functions with and without a time lag are then deduced by a simple probabilistic argument. Results are derived in the Markov case and are partly extended to the semi-Markov case.

Bull. math. Biol. Vol. 47, No. 2, pp. 193–204, 1985

NON-LINEAR COMPARTMENTAL SYSTEMS: EXTENSIONS OF S. R. BERNARD'S URN MODEL

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Abstract—One of the limitations of stochastic, linear compartmental systems is the small degree of variability in the contents of compartments. S. R. Bernard's (1981) urn model (S. R. Bernard *et al.*, *Bull. math. Biol.* **43**, 33–45.) which allows for bulk arrivals and departures from a one-compartment system, was suggested as a way of increasing content variability. In this paper, we show how the probability distribution of the contents of an urn model may be simply derived by studying an appropriate set of exchangeable random variables. In addition, we show how further increases in variability may be modeled by allowing the size of arrivals and departures to be random.

J. math. Biol. Vol. 22, pp. 117–120, 1985

PROPORTIONATE MIXING MODELS FOR AGE-DEPENDENT INFECTION TRANSMISSION

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Abstract—We present explicit formulas for the transmission potential of an immunizing infection where the contact rates and the vaccination rates depend on the chronological age of an individual, and the infectivity and the recovery rate depend on the duration of an infection.

Key Words—Epidemiology, endemic infectious diseases, age-dependent contact rates, transmission potential.

Adv. appl. Probabil. Vol. 17, pp. 424–442, 1985

COMPUTING OPTIMAL (s, S) POLICIES IN INVENTORY MODELS WITH CONTINUOUS DEMANDS

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Abstract—Special algorithms have been developed to compute an optimal (s, S) policy for an inventory model with discrete demand and under standard assumptions (stationary data, a well behaved one-period cost function, full backlogging and the average cost criterion). We present here an iterative algorithm for continuous demand distributions which avoids any form of prior discretization. The method can be viewed as a modified form of policy iteration applied to a Markov decision process with continuous state space. For phase-type distributions, the calculations can be done in closed form.

Policy iteration.

J. math. Biol. Vol. 22, pp. 21–29, 1985

THE WRIGHT–FISHER MODEL WITH TEMPORALLY VARYING SELECTION AND POPULATION SIZE

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Abstract—The Wright–Fisher model is considered in the case where the population size is random and the magnitude of the selective advantage of one of the alleles varies with time. The central question addressed is the possibility of ultimate genetic polymorphism. Partial results are obtained in the general case and complete results in the case where the population size and selective advantage are not density dependent. Bounds on the fixation probability are obtained when the selective advantage is constant.

Key Words—Wright–Fisher model, selective advantage, ultimate homozygosity, martingale methods, coupling techniques, fixation.

J. Am. statist. Ass. Vol. 80, No. 389, March 1985

MODELING AGREEMENT AMONG RATERS

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Abstract—An approach to the modeling of agreement among raters is proposed. By examining a hierarchy of log-linear models, it is shown how one can analyze the agreement among the raters in a manner analogous to the analysis of association in a contingency table. Specific attention is given to the problems of the K-rater agreement and the agreement between several observers and a standard. Examples are used to illustrate how this approach provides a general framework for modeling agreement in a variety of problem situations.

Key Words—Agreement, kappa, log-linear models, categorical data.

Technometrics Vol. 27, No. 2, May 1985

AN EXAMINATION OF RESPONSE-SURFACE METHODOLOGIES FOR UNCERTAINTY ANALYSIS IN ASSESSMENT MODELS

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Abstract—Two techniques of uncertainty analysis were applied to a mathematical model that estimates the dose-equivalent to man from the concentration of radioactivity in air, water, and food. The response-surface method involved screening of the model to determine the important parameters, development of the response-surface equation, calculating the moments using the response-surface model, and fitting a Pearson or Johnson distribution using the calculated moments. The second method sampled model inputs by Latin hypercube methods and iteratively simulated the model to obtain an empirical estimation of the cdf. Comparison of the two methods indicates that it is often difficult to ascertain the adequacy or reliability of the response-surface method. The empirical method is simpler to implement and, because all model inputs are included in the analysis, it is also a more reliable estimator of the cumulative distribution function of the model output than the response-surface method.

Key Words—Uncertainty analysis, experimental design, response surfaces, factorial design, Latin hypercube sampling, distribution fitting.

GROWTH MODELS WITH STOCHASTIC DIFFERENTIAL EQUATIONS. AN EXAMPLE FROM TUMOR IMMUNOLOGY

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Abstract—The effects of demorgraphic and environmental stochasticity on the qualitative behavior of a mathematical model from tumor immunology are studied. The model is defined in terms of a stochastic differential equation whose solution is a limiting diffusion process to a branching process with random environments.

Biol. Cybern. Vol. 53, pp. 93–108, 1985

AN IMPROVED NEURAL-NETWORK MODEL FOR THE NEURAL INTEGRATOR OF THE OCULOMOTOR SYSTEM: MORE REALISTIC NEURON BEHAVIOR

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J. Am. statist. Ass. Vol. 80, No. 389, March 1985

A STATISTICAL MODEL FOR POSITRON EMISSION TOMOGRAPHY

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Abstract—Positron emission tomography (PET)—still in its research stages—is a technique that promises to open new medical frontiers by enabling physicians to study the metabolic activity of the body in a pictorial manner. Much as in X-ray transmission tomography and other modes of computerized tomography, the quality of the reconstructed image in PET is very sensitive to the mathematical algorithm to be used for reconstruction. In this article, we tailor a mathematical model to the physics of positron emissions, and we use the model to describe the basic image reconstruction problem of PET as a standard problem in statistical estimation from incomplete data. We describe various estimation procedures, such as the maximum likelihood (ML) method (using the EM algorithm), the method of moments, and the least squares method. A computer simulation of a PET experiment is then used to demonstrate the ML and the least squares reconstructions. The main purposes of this article are to report on what we believe is an important contribution of statistics to PET and to familiarize statisticians with this exciting field that can benefit from further statistical methodologies to be developed with PET problems in mind. Thus no background in physics or previous knowledge of computerized tomography is assumed. The emphasis is on the basic PET model and the statistical methodology needed for it.

Key Words—Poisson point process, estimation, least squares, maximum likelihood, Stein-type estimators, EM algorithm, image reconstruction, incomplete data, nuclear medicine.